MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

EME4016 – HEAT TRANSFER
(ME)

28 FEBRUARY 2020
3:00 p.m. – 5:00 p.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question Paper consists of six pages including the cover page and appendix.
2. Answer ALL four questions. Each question carries 25 marks and the distribution of the marks for each question is given in brackets [ ].
3. Write all your answers in the Answer Booklet provided.

Question 1

(a) Consider one-dimensional steady heat conduction in a long solid cylinder of radius R and thermal conductivity k that contains a uniformly distributed heat source of $\dot{q}$ W/m^3. If the surface temperature is kept at a constant T_w, show that the temperature in the cylinder is given by

$$T = T_w + \frac{\dot{q}R^2}{4k}\left[1 - \left(\frac{r}{R}\right)^2\right]$$

Take the applicable conduction equation in the cylinder as

$$\frac{k}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right) + \dot{q} = 0.$$

[10 marks]

(b) In one type of nuclear reactor the fuel elements consists of long cylindrical uranium rods sheathed or covered in thin light alloy tubes. These tubes are cooled by a stream of gas and the effective overall heat transfer coefficient from the uranium to the gas, based on the outside surface area, is 900 $W/m^2{\cdot}K$. If the heat is generated uniformly in the uranium at the rate of $2.0{\times}10^7$ W/m^3 and if the coolant gas temperature is 350 ^oC, estimate the rod diameter which gives a maximum permissible uranium temperature of 600 ^oC. Take the thermal conductivity of uranium as 29.8 $W/m{\cdot}K$. *Hint: Ignore the tube in your conduction analysis.*

[15 marks]

Continued...

Question 2

(a) A metal slab of length 0.1 *m* and width 0.2 *m* is inserted at the center of a wooden plate of length 0.5 *m* and width 0.2 *m*. Consider a turbulent airstream at a temperature of 20 °*C* and a velocity of 10 *m/s* that flows over the entire length of the plate. A heat source is attached to the lower side of the plate to maintain isothermal condition over the entire plate. *(Please refer to the appendix for the properties table)*

(i) Determine the total heat transfer rate that transferred to the metal slab in order to maintain the metal slab surface temperature at constant 50 °*C*. **[10 marks]**

(ii) If the air blower that maintains the airstream velocity is malfunctions, but other conditions remain unchanged as stated in the question, estimate the surface temperature of the metal slab and explain if the estimated value can be accepted. *Hint: Assume a film temperature.* **[15 marks]**

Table Q2: Nusselt number correlations

Correlation	Conditions
$Nu_x = 0.332\,\mathrm{Re}_x^{1/2}\,\mathrm{Pr}^{1/3}$	Laminar flow
$Nu_x = 0.0296\,\mathrm{Re}_x^{4/5}\,\mathrm{Pr}^{1/3}$	Turbulent flow
$\overline{Nu} = 0.54 Ra_L^{1/4}$	$10^4 \le Ra_L \le 10^7$; $L \equiv \frac{A_s}{P}$
$\overline{Nu} = 0.15 Ra_L^{1/3}$	$10^7 \le Ra_L \le 10^{11}$; $L \equiv \frac{A_s}{P}$

Continued...

Question 3

(a) A long circular aluminum fin is attached at one end to a heated wall and transfers heat by convection to a cold fluid.

(i) Obtain an expression to describe the heat transfer rate from the fin. *Hint: Please utilize the given fin temperature profile.*

$$\frac{T(x) - T_\infty}{T_b - T_\infty} = e^{-mx}$$

[5 marks]

(ii) With reference to the answer obtained from **part (i),** How much would the heat transfer rate be enhanced if the diameter of the fin is doubled? **[4 marks]**

(b) A cross flow heat exchanger is used in a cardiopulmonary bypass procedure to cool the blood flowing at a rate of 6000 *ml* per minute from a body temperature of 37 °*C* to 25 °*C*, to induce body hypothermia. Ice water at 0 °*C* is applied as a coolant and its outlet temperature is expected to be 20 °*C*. Both the blood and the ice water are unmixed. The overall heat transfer coefficient is $750\ W/m^2K$. The blood properties are given as $\rho = 1050\ kg/m^3$ and C_p = 3740 *J/kg.K*. The water properties are given as $\rho = 1000\ kg/m^3$ and C_p = 4198 *J/kg.K*.

(i) Determine the volumetric flow rate of the water. **[8 marks]**

(ii) Determine the effectiveness of the heat exchanger. **[5 marks]**

(iii)The overall heat transfer coefficient of the cross flow heat exchanger used in a cardiopulmonary bypass reduces with time. Name this phenomenon and identify the possible factors. **[3 marks]**

Continued...

Question 4

(a) Define the view (or shape) factor $F_{1\text{-}2}$ for radiation from body 1 to body 2. What is its relation to the complementary factor $F_{2\text{-}1}$?

[4 marks]

(b) A special furnace is in the shape of a long triangular section channel. If the shape of the triangle is equilateral, show that the view factor between any two sides is 0.5. If the triangle is not equilateral, find an expression for $F_{1\text{-}2}$ in terms of the side areas A_1, A_2 and A_3, for sides 1, 2, and 3, respectively. Hence evaluate $F_{1\text{-}2}$ in the case of $A_1 = 5\ m^2$, $A_2 = 4\ m^2$ and $A_3 = 3\ m^2$.

[10 marks]

(c) A convex body of surface area 1 m^2, emissivity 0.8 and temperature 900 K is totally enclosed by a body of surface area 3 m^2, emissivity 0.7 and temperature 700 K. Evaluate the net radiative heat transfer rate between these bodies. Take the Stefan-Boltzmann constant as $5.67\times10^{-8}\ W/m^2{\cdot}K^4$.

[11 marks]

Continued...

Appendix: Properties of air at 1 atm pressure

Properties of air at 1 atm pressure

Temp., T, °C	Density, ρ, kg/m^3	Specific Heat, C_p, J/kg · °C	Thermal Conductivity, k, W/m · °C	Thermal Diffusivity, α, m^2/s	Dynamic Viscosity, μ, kg/m · s	Kinematic Viscosity, ν, m^2/s	Prandtl Number, Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-6}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
90	0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
100	0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
120	0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
140	0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
160	0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
180	0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
200	0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
250	0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
300	0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935
350	0.5664	1056	0.04721	7.892×10^{-5}	3.101×10^{-5}	5.475×10^{-5}	0.6937
400	0.5243	1069	0.05015	8.951×10^{-5}	3.261×10^{-5}	6.219×10^{-5}	0.6948
450	0.4880	1081	0.05298	1.004×10^{-4}	3.415×10^{-5}	6.997×10^{-5}	0.6965
500	0.4565	1093	0.05572	1.117×10^{-4}	3.563×10^{-5}	7.806×10^{-5}	0.6986
600	0.4042	1115	0.06093	1.352×10^{-4}	3.846×10^{-5}	9.515×10^{-5}	0.7037
700	0.3627	1135	0.06581	1.598×10^{-4}	4.111×10^{-5}	1.133×10^{-4}	0.7092
800	0.3289	1153	0.07037	1.855×10^{-4}	4.362×10^{-5}	1.326×10^{-4}	0.7149
900	0.3008	1169	0.07465	2.122×10^{-4}	4.600×10^{-5}	1.529×10^{-4}	0.7206
1000	0.2772	1184	0.07868	2.398×10^{-4}	4.826×10^{-5}	1.741×10^{-4}	0.7260
1500	0.1990	1234	0.09599	3.908×10^{-4}	5.817×10^{-5}	2.922×10^{-4}	0.7478
2000	0.1553	1264	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

Note: For ideal gases, the properties C_p, k, μ, and Pr are independent of pressure. The properties ρ, ν, and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Keenan, Chao, Keyes, Gas Tables, Wiley, 198; and Thermophysical Properties of Matter, Vol. 3: Thermal Conductivity, Y. S. Touloukian, P. E. Liley, S. C. Saxena, Vol. 11: Viscosity, Y. S. Touloukian, S. C. Saxena, and P. Hestermans, IFI/Plenun, NY, 1970, ISBN 0-306067020-8.

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